FDTD Antenna Modeling for Ultrawideband Electromagnetic Remote Sensing

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By

SLEIMAN EL HAGE GHONEIN

Faculty Advisor

Prof. Fernando L. Teixeira

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I. ABSTRACT

This paper is intended to explain and present the result for the research conducted on time reversal phenomenon for electromagnetic waves in presence of an array of three bowtie antennas. The research was conducted by software using Finite-Difference Time-Domain technique.

II. INTRODUCTION

These days the demand on sensing technologies is increasing rapidly. Such increase in demand is due mainly to the essential role that sensing technologies play in safety of victims, hostages, and security forces. For example, rescue teams must be able to locate hidden survivors under collapsed buildings, landslides, debris, and other situations. Also, fire fighters require sensing technologies to track inside building under low visibility.

The sensing technologies available these days, depend mainly on microwave and millimeter wave systems. The full exploitation of such systems still faces fundamental barriers. Such frequencies are vulnerable to certain atmospheric and meteorological activity and to attenuation inside lossy materials. Moreover, electromagnetic wave scattering and propagation in such problems most often occur in disordered media. In other words, media where the intervening media has complex constitutive properties, and/or many scatters are present between the transmitters and receivers and /or precise information about their location and constitutive properties is not available. As a result, the signal from the targets is often weak and distorted by clutter and multipath (multiple scattering), which confounds detection, causes erratic tracking and makes it difficult to extract relevant information for imaging and classification purposes. The lack of precise information about the intervening media implies that the medium cannot be treated deterministically and a statistical model needs to be employed instead.

The use of ultrawideband (UWB) systems is attractive to overcome challenges mentioned above. UWB systems can exploit advantages of simultaneous operation at both low (more penetration into lossy materials) and high frequencies (larger resolution). Also, UWB signals are more immune to atmospheric effects, which are frequency dependent. Moreover, UWB signals are more immune to effects of multipath interference. Finally, UWB sensing systems can explore time-domain statistical stability in random media, that is, UWB allow for developing imaging techniques that depend only on the statistical properties of the intervening random medium and not its detailed structure.

Therefore, form what has proceeded, it can be seen how advantageous UWB remote sensing is. Thus the advantage of conducting such a research is that its outcomes serve UWB remote sensing applications.

III. OBJECTIVES

The main objectives for this research can be summarized as:

1. Simulation of the propagation of UWB electromagnetic signals using the 3D Finite-Difference Time-Domain (FDTD) employing Uniaxial Perfectly Matched Layer (UPML) technique.
2. Implementation of bowtie antenna using the FDTD method.
3. Examining the Time Reversal phenomenon in a homogeneous medium with no antennas present.

4. Examining the Time Reversal phenomenon in a homogeneous medium with an array of three bowtie antennas present.

IV.TIME REVERSAL

A major technique exploited in this research is Time Reversal (TR). Time reversal was first introduced by Mathis Fink for acoustics. The idea behind time-reversal is that if a wave is sent and recorded by a number of receivers, then if the data recorded by each receiver is time reversed (or played backwards) then the transmitted waves will focus at a point where the source was originally placed. The figure in Fink's paper [1] below shows an example of time reversal for acoustics. The yellow strip represents a number of transducers that record the incident "Hello" wave. Then the transducers time reverse the recorded data and transmit them. Thus the sent "olleH" signal focus back to the mouth of the person rather than spreading throughout space.

Physical time-reversal (TR) techniques which were recently introduced by Fink et al. [1] have shown potential for ultra-wideband (UWB) remote sensing applications. Although these techniques were first developed using acoustic waves, they can also be applied to electromagnetic (EM) waves since they are based on the invariance of wave equations under time reversal in lossless media.

V. FINITE DIFFERENCE TIME DOMAIN

In this research the Finite Difference Time Domain (FDTD) is the main tool for simulations done in C++ programming language.

Finite Difference Time Domain (FDTD) is a numerical technique used to solve Maxwell equations. It modifies Maxwell equations into central-difference equations, discretize them, and allows them to be implemented in software. The unique feature of FDTD is that it is a Time-domain technique and, thus, it can cover a wide frequency range with single simulation.

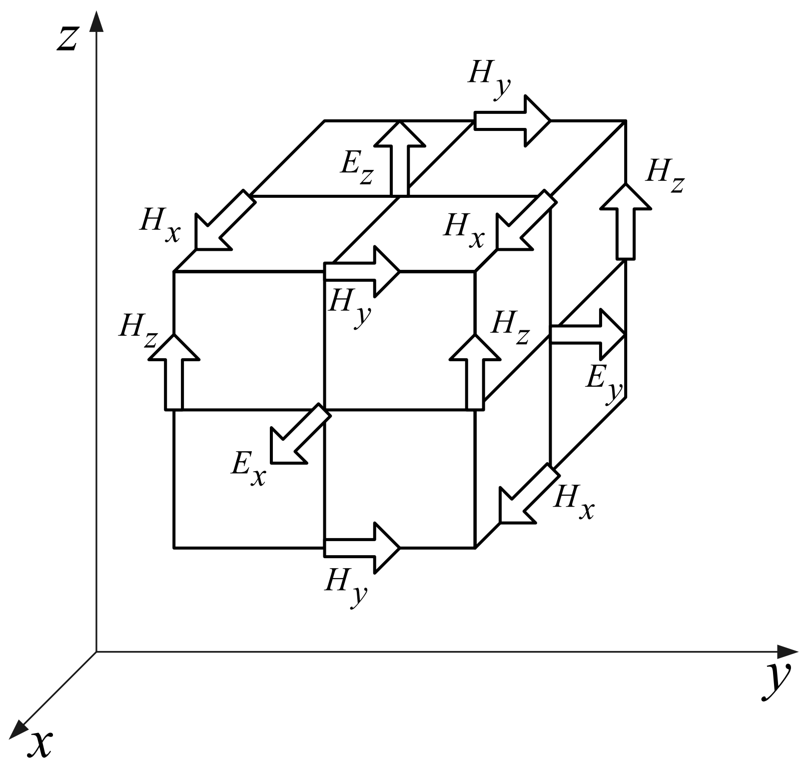

Figure 2: Yee's lattice

The algorithm used is known as Yee Algorithm. This algorithm solves for both electric and magnetic fields in time and space using the coupled Maxwell's equations rather than solving for the electric field alone (or magnetic field alone) with a wave equation [3]. Moreover, the Yee algorithm centers its E and H components in three-dimensional space so that every E component is surrounded by four circulating H components, and every H component is surrounded by four circulating E components.

Figure 2 above shows the E and H components displacement over what's known as Yee's Lattice.

VI. PERFECTLY MATCHED LAYER

Another key feature used in to perform simulations in this research is the Perfectly Matched Layer (PML). The paragraph below presents some illustration about PML.

As mentioned earlier, in this research, waves are simulated by software using FDTD. Since the wave physically propagates to infinity, the simulation should also reveal such infinite propagation of an EM wave. Therefore, due to limitation on the amount of data a computer and store, we need a boundary condition that permits simulation of wave extension to infinity. Thus, the boundary condition must suppress spurious reflections of the outgoing numerical waves.

The PML is a layer used to surround the simulations computational domain in order to simulate infinite wave propagation. It represents an anechoic chamber providing reflectionless propagation for all impinging waves (any incident angle) over their full frequency spectrum. Thus, plane waves of arbitrary incidence, polarization, and frequency are matched at the boundary.

It should be noted that simulations done for this research use the Uniaxial Perfectly Matched Layer (UPML). The UPML plays the same role as PML. The unique feature of UPML is that it is composed of electric and magnetic permittivity tensors.

VII. OVERVIEW OF COMPUTATIONAL DOMAIN

Figure 3 below presents an overview of the computational domain used for the simulations done in this research. The figure shows how the domain is surrounded by the UPML, which is few lattice cells thick. It should be noted that the UPML is terminated by a Perfect Electric Conductor that is used to set the tangential components of the electric field to zero.

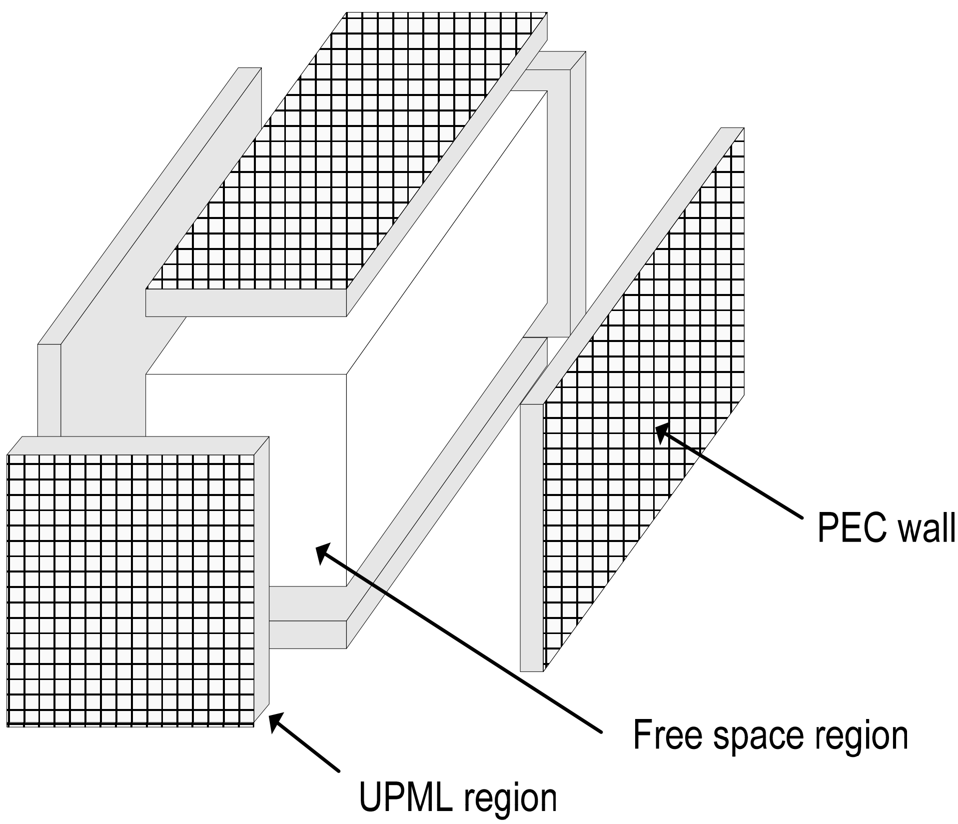

Figure 3: Computational domain used for simulations

VIII. ANTENNA/SOURCE SETUP

The figures below, show the top, side, and 3-D view of the way the antennas and the source were placed.

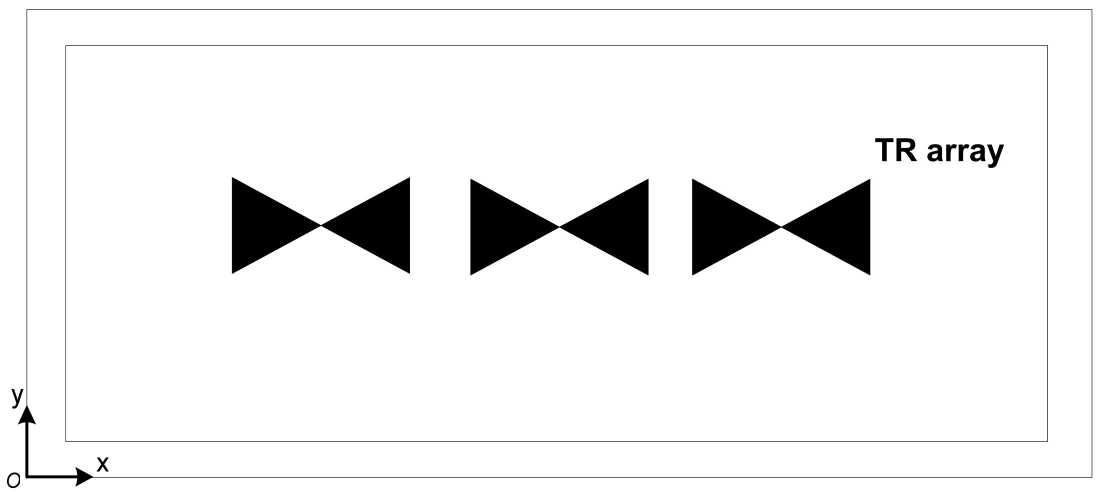

Figure 4: Top View

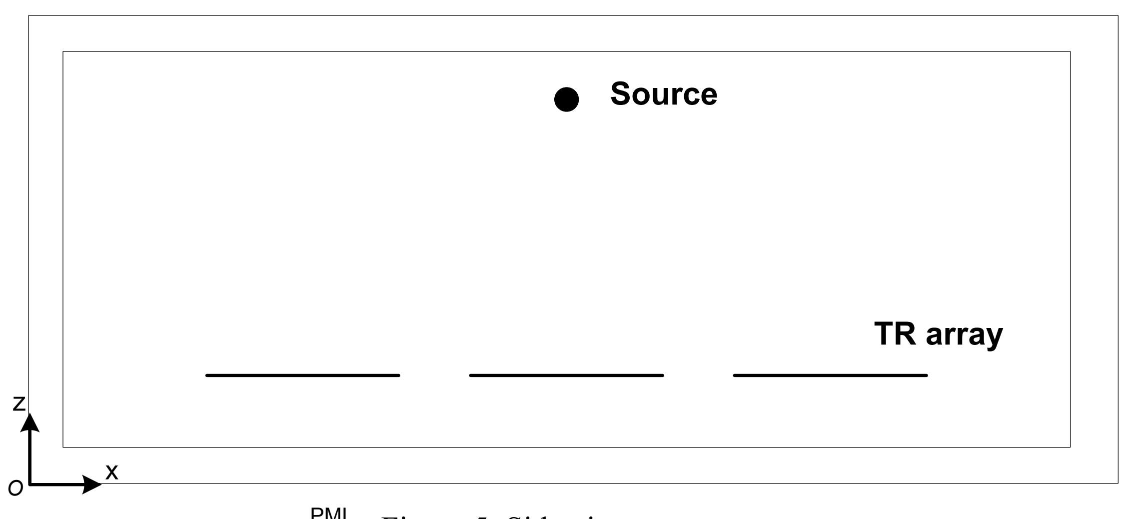

Figure 5: Side view

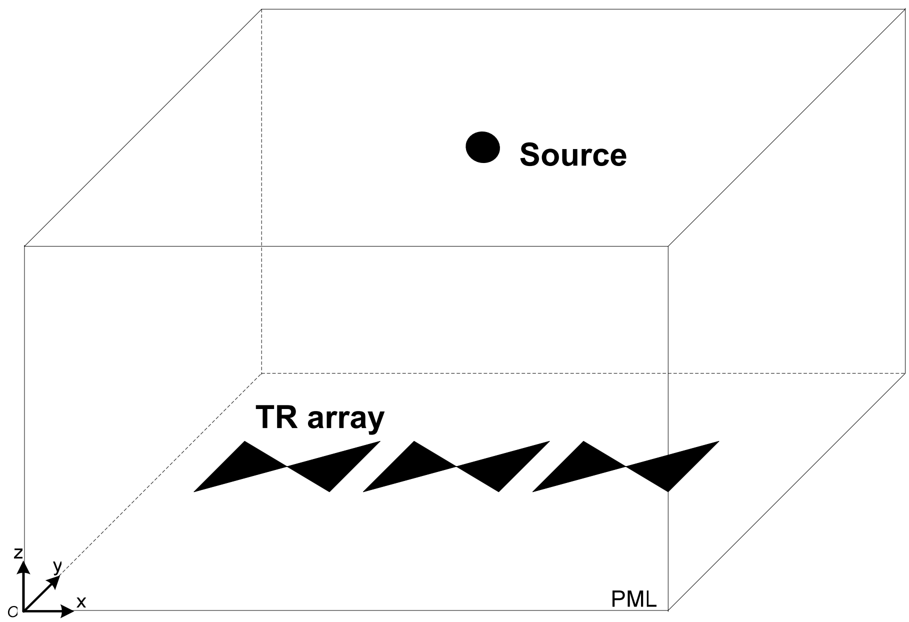

Figure 6: 3-D view

IX. BOWTIE ANTENNA IMPLEMENTATION

Figure 7 below shows the Ex and Ey components inside the antenna's arms. Those components were set to zero by code in order to implement the bowtie antenna. Note that each angle of the antenna's arm is 60 degrees.

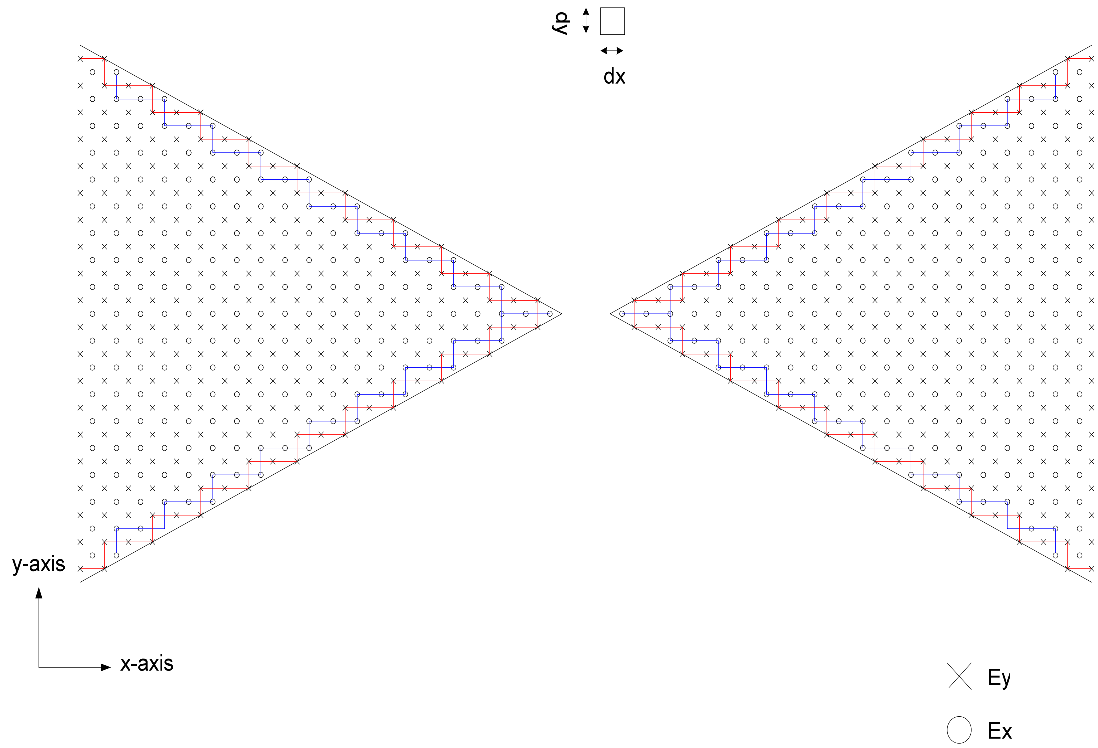

Figure 7: Bowtie Antenna

It can be seen from figure 7 how the edges of the arms were stair cased. Note also that the gap between the arms of the antenna is 2 lattice cells long. When the antenna is used to transmit, the source would be placed in the middle of the gap. Similarly, when the antenna is used for receiving signals, the point at the middle of the gap is used as a receiver to record data.

VIII. SOURCE AND VARIABLES

For this research several simulations were done (please refer to the simulations section for details on each simulation performed). Each simulation consisted of a forward propagation and a time reversed propagation for such a forward propagation. This section presents information about the source and major variables used for the conducted simulations.

Source

An ideal x-polarized point source was used in all forward propagations. The signal transmitted by such a source was the first derivative of the Blackmann-Harris pulse with a central frequency of 400 MHz. The unique feature of this pulse is that it is an UWB pulse with no DC component, where the DC component, if present, would produce distortion in the simulation. Also this UWB pulse contains both low frequency, resulting in deeper penetration, and high frequency, resulting in better resolution. Figure 8 shows both the time and frequency domain of the first derivative of the Blackmann-Harris pulse.

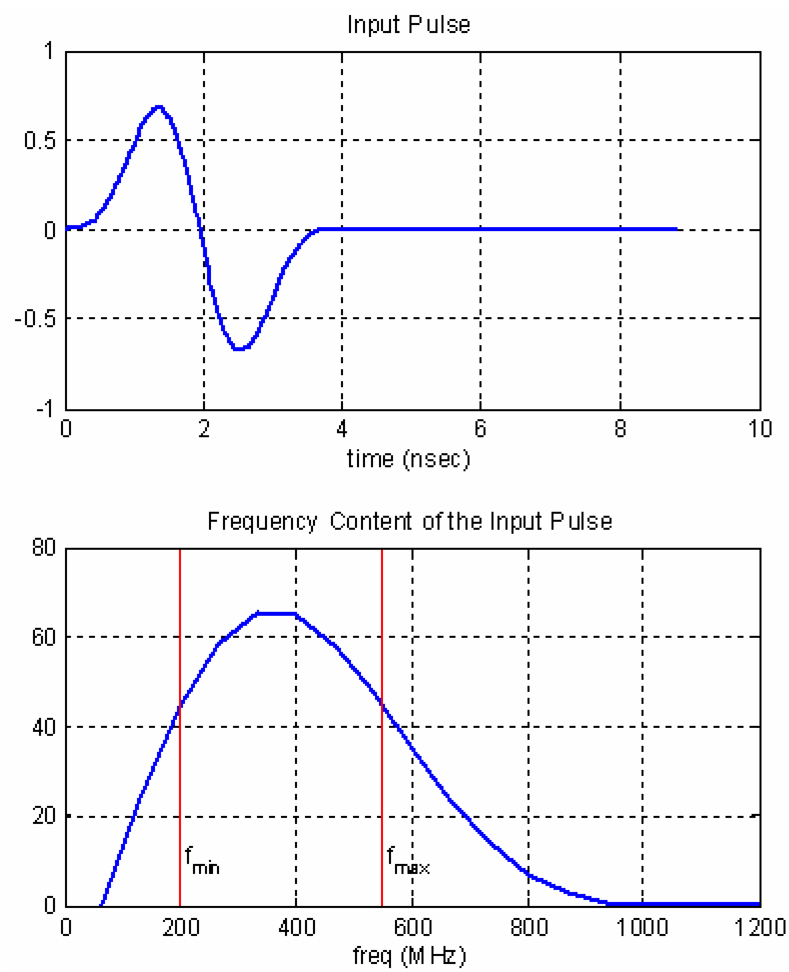

Figure 8

Variables

An important variable to be mentioned here is that simulations were done with 40 spatial steps per the central wavelength. Also the medium was a lossless medium with electric permittivity of 5.5 (which is almost same as soil). Finally, it should be noted that the length of each antenna was equal to two times the max wavelength.

IX. SIMULATIONS

This section shows the simulations performed in this research. Five major simulations are described, where each simulation has a forward propagation and the time reversed propagation for such a forward propagation. In the forward propagation data is collected. Such data is time reversed and sent back in the time reversed propagation. Note the time reversing the collected can be implemented simply by reversing the collected data, i.e. sending data backwards.

i. First Try

The first simulation was done with no antennas present. In this simulation only ideal source and receivers were used in order to show the occurrence of time reversal. Figure 8 below shows a shot of the forward propagation for this try. Note that the source for this simulation was placed at the point with coordinates (75,120).

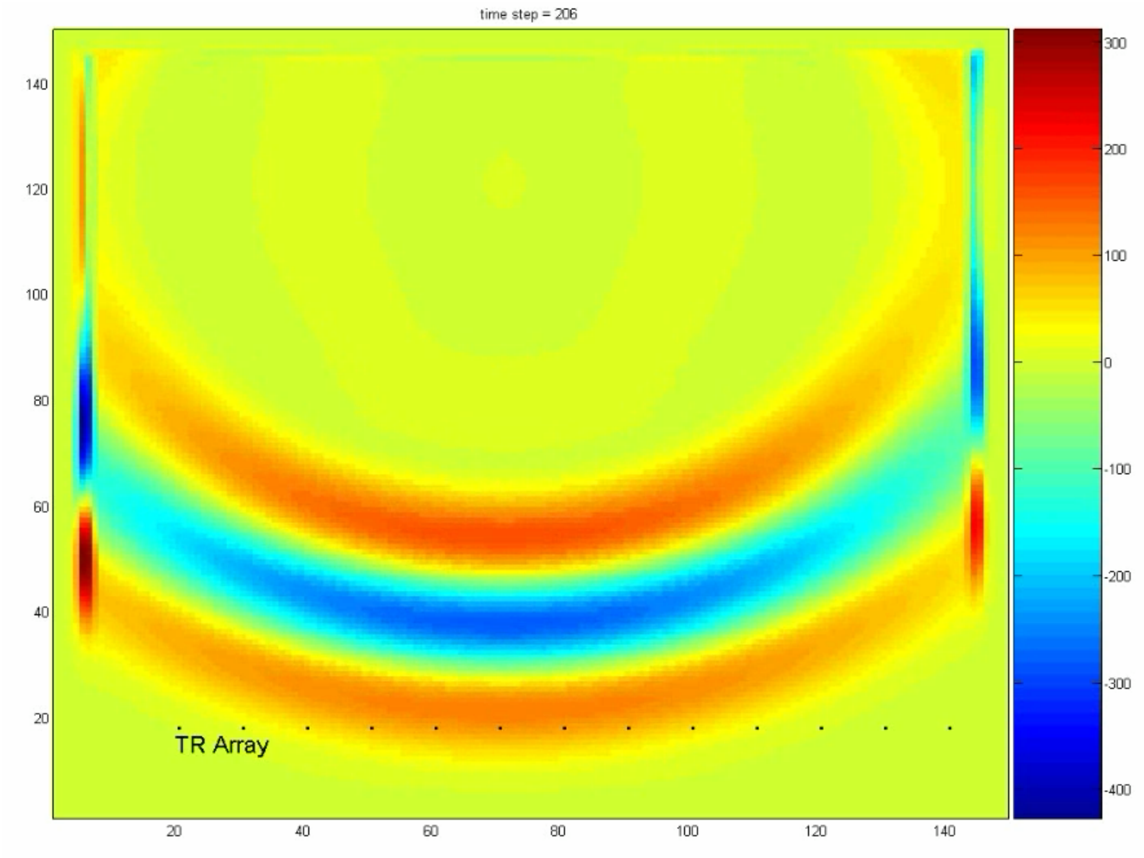

Figure 9: Forward Propagation of ideal case

It can be seen from figure 9 that 13 receivers constitute the TR array. This array records data from forward propagation so that this data will be used for time reversed simulation.

Figure 10 below shows a screen shot of the time reversed simulation. It can be seen how the time reversed wave have focused over the point where the source was originally placed.

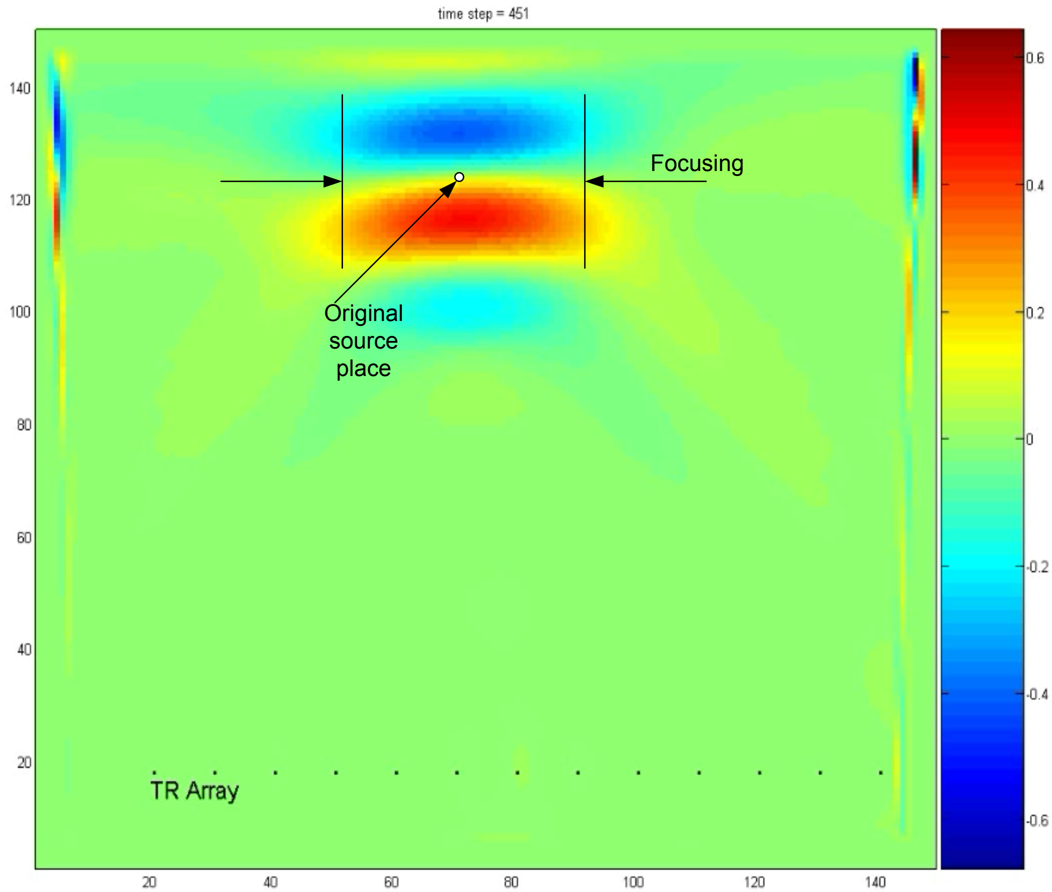

Figure 10: Time Reversed Signal

ii. Second try

This simulation was the first simulation conducted in presence of antenna array (3 bowtie antennas). The source was placed right above the right most antenna, at point (475, 60), thus the distance between the source and the array was about half wavelength. The array was place along the line y=20. Figures 11 and 12 show snap shots of the forward propagation and figure 13 shows a snap shot of the time reversed propagation.

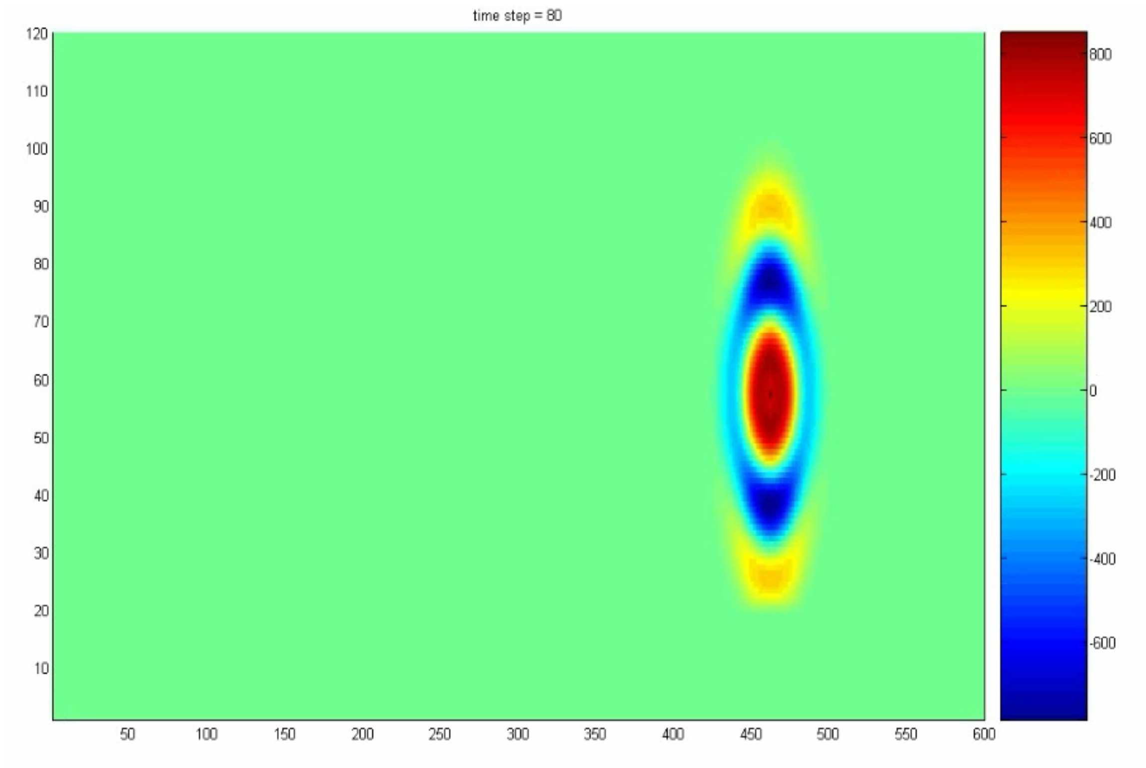

Figure 11

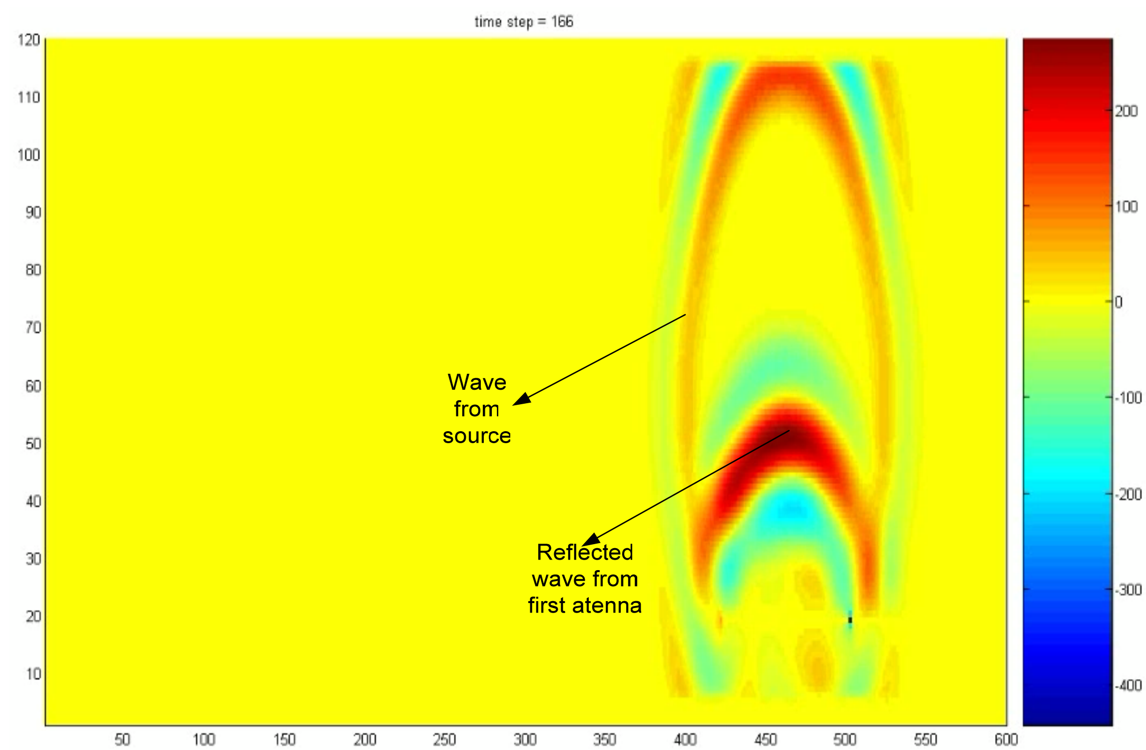

Figure 12

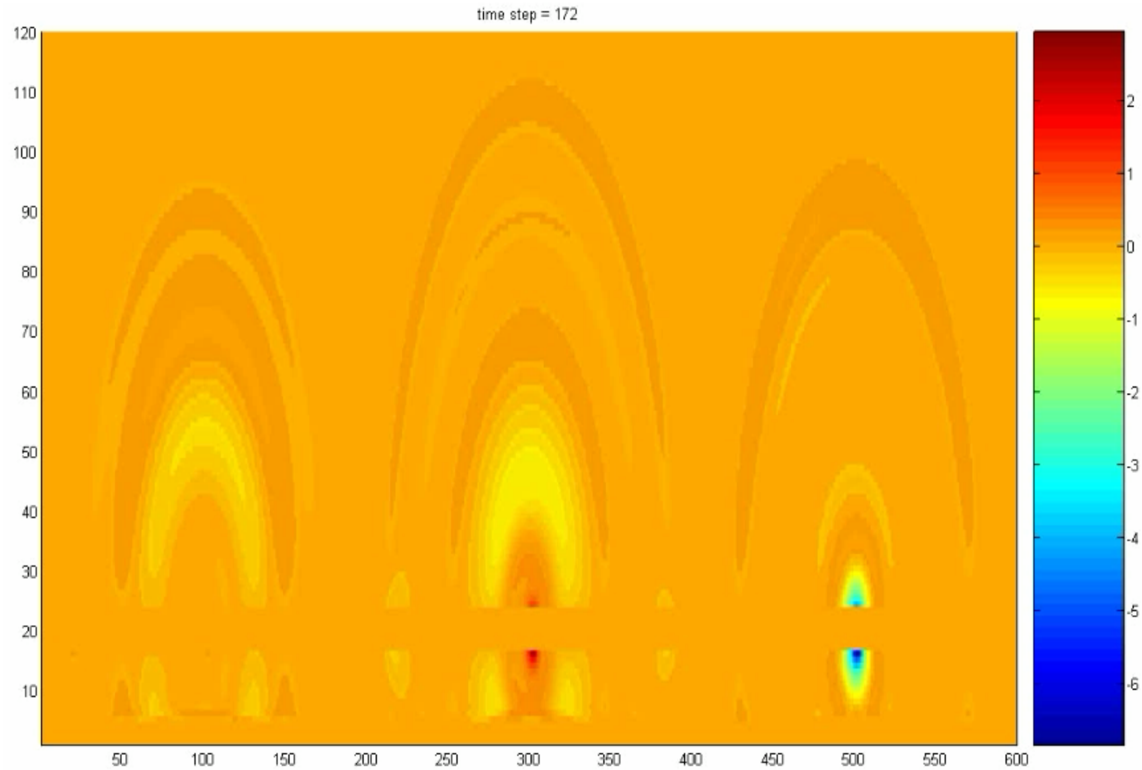

Figure 13: Time Reversed Propagation

This try was not successful in terms of achieving focusing at the source point. It can be seen from forward propagation figures (11 and 12) that the antennas received reflections from other antennas rather than receiving the incident wave from the source. That is due to the short distance between the source and the right most antenna. That has lead to having no focusing in the time reversed propagation (Figure 13).

iii. Third Try

In this try the source was placed above the middle antenna at a height almost equal to one wavelength.

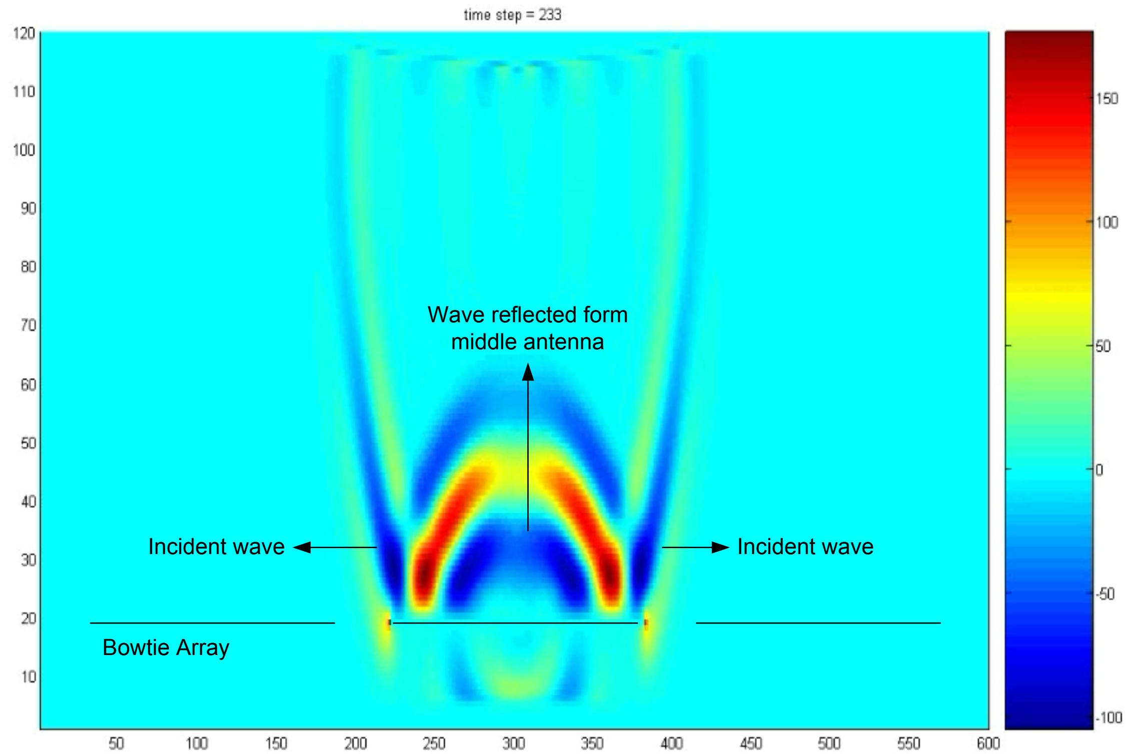

Figure 14: Forward propagation

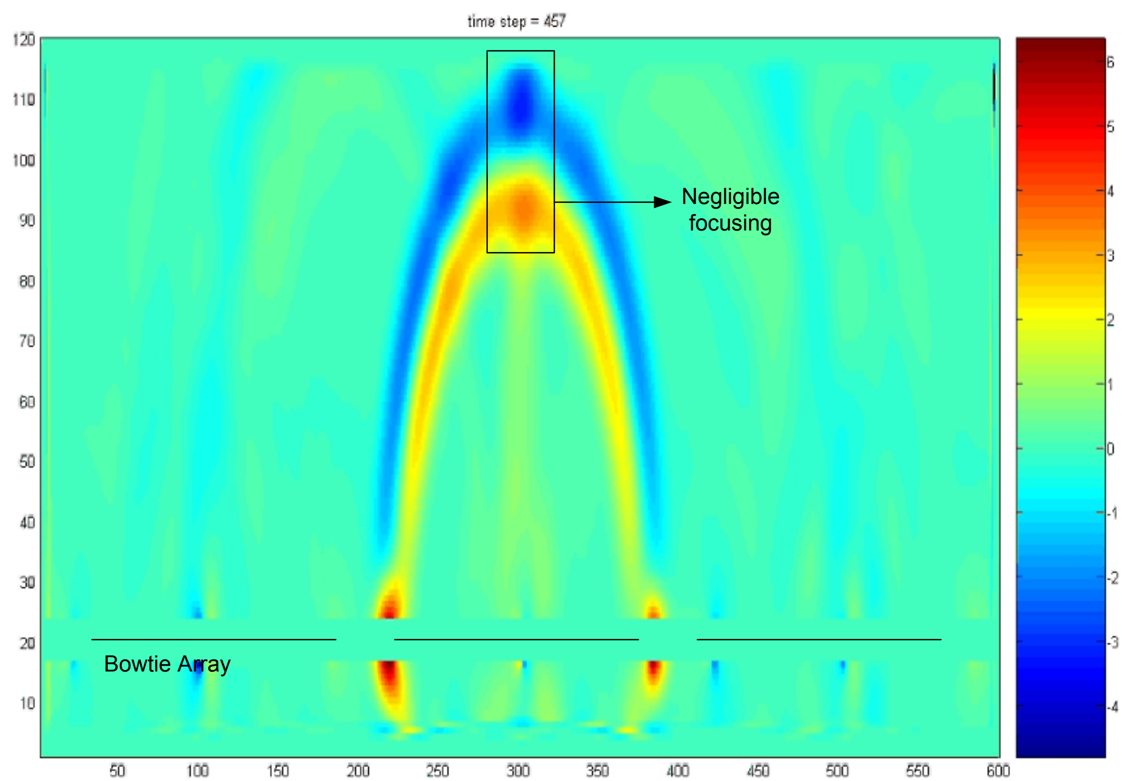

Figure 15: Time reversed Propagation

The time reversed propagation of this try has achieved insignificant focusing (Figure 15). Thus it was not enough to achieve the goal of this research.

iv. Fourth Try

In this try the source placed above the middle antenna at a height almost equal to four wavelengths.

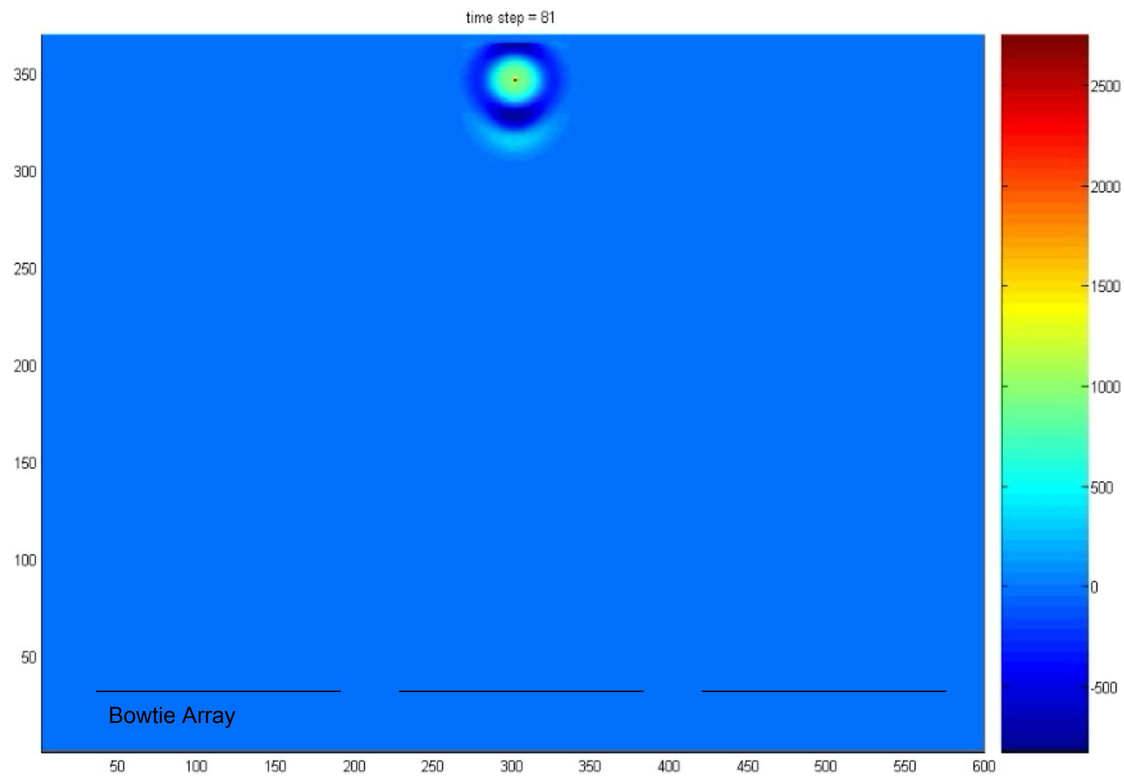

Figure 16: Forward Propagation (1st shot)

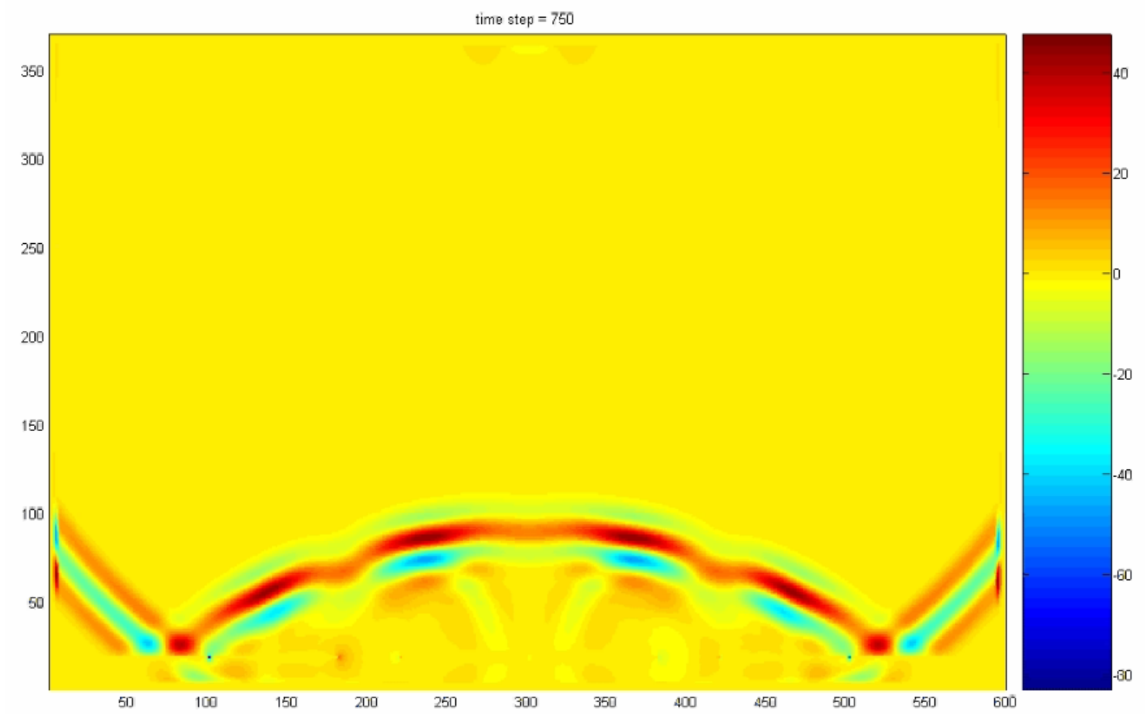

Figure 17: Forward Propagation

Figures 16 and 17 show two snap shots of the forward propagation. In figure 17 the incident wave has reflected after hitting the antennas.

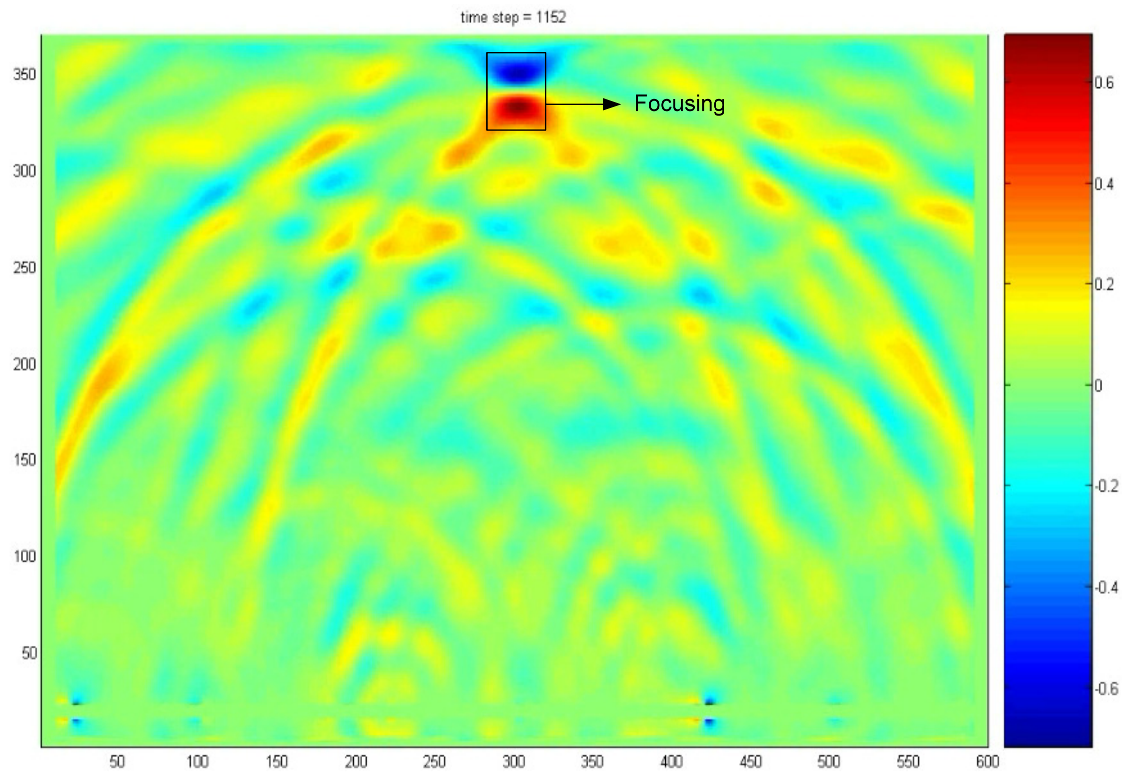

Figure 18: Time reversed propagation

Figure 18 above shows the time reversed propagation. This simulation revealed significant focusing at the point where the source was initially placed. Therefore focusing with time reversal has been accomplished.

v. Final Try

We have noticed from simulations one and two, that the coupling between the antenna prevented us from achieving focusing in time reversal propagation. Therefore in this simulation an approach was tried to prevent the coupling between antennas. The approach was to run the forward propagation for each antenna separately. Then the data collected from each antenna was combined and run simultaneously for time reversal. The result for such approach is shown below.

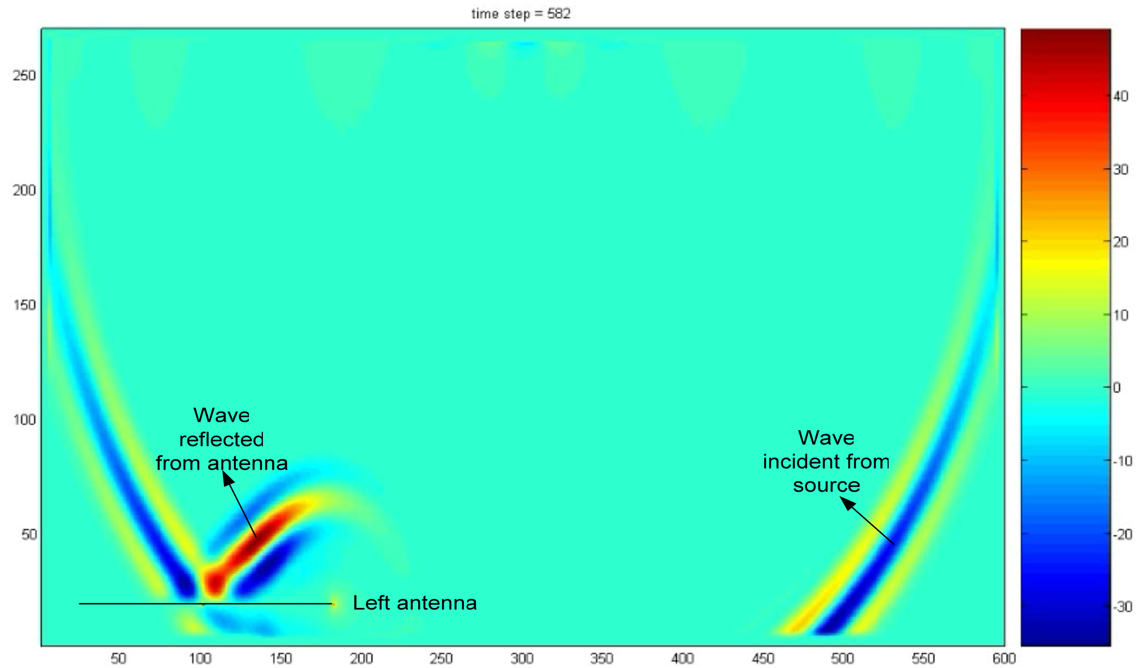

Figure 19: Forward propagation (Left antenna)

Figure 19 shows the forward propagation with the left antenna present only. Such propagation is repeated for each antenna (as mentioned above).

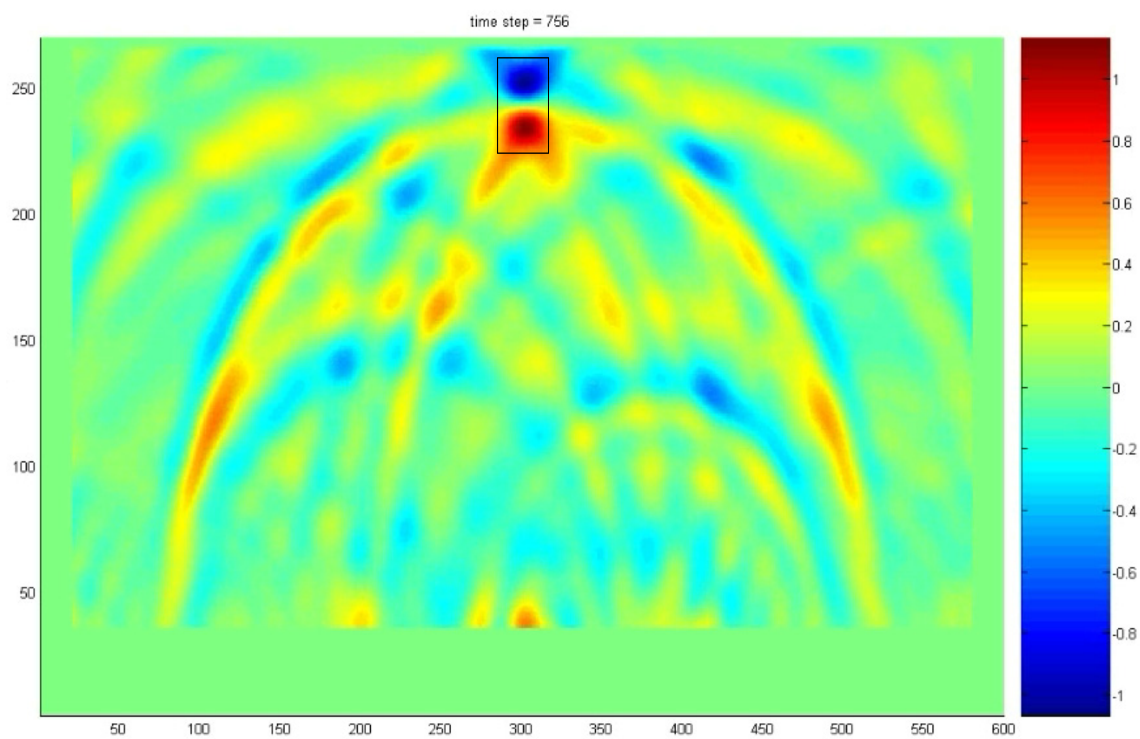

Figure 20: Time reversed propagation

Figure 20 shows the results for the antenna decoupling approach we used. The figure shows that focusing occurs at the point where the source was initially placed.

X. RESULTS

The simulations presented provide several results about wave propagation and time reversal in presence of the bowtie antenna array. First, the distance between source and antennas array has a great effect on occurrence of focusing. In fact, as simulations revealed, focusing did not occur when the distance between the source and array was less than one wavelength (second try). Also an insignificant focusing occurred when the distance was one wavelength (third try). Wave reflected from antennas produces much noise when source is close to array, and prevents focusing to occur.

Second, when source is placed close to antenna array, antenna coupling dominates the medium and therefore prevents significant data about the source to be collected. Thus no focusing occurs in time reversal.

Finally, increasing the distance between the source and array allows each antenna to receive the original wave will less noise. Therefore better focusing occurred in time reversed propagation. Significant focusing occurred in the fourth and fifth tries where the distance between the source and antenna array was relatively large.

XI. CONCLUSION AND FUTURE WORK

This research has accomplished its objectives. EM waves propagation was simulated using FDTD. Also, Bowtie Antennas have been implemented by software. Moreover, time reversal for EM wave was examined with and without presence of an array of three bowtie antennas. Finally, the simulations have revealed the occurrence of focusing in time reversed propagations.

The future works for this project can be improving the antennas by adding resistive sheets. Also antenna can be implemented with coaxial cables added. In addition, the effect of the geometry of antenna on focusing can be examined. Finally, the effect of antenna direction on focusing can also be examined.

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